ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 144
15 November 1954

METHOD FOR STUDYING PERFORMANCE ON A SAMPLE TRACKING TASK AS A FUNCTION OF RADIUS AND LOADING OF CONTROL CRANKS*

*Subtask under Human Engineering Studies, AMRL Project No. 6-95-20-001, Subtask, Control Coordination Problems. Work done at the University of Rochester under Contract No. DA-49-007-MD-326.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

Army Medical Research Lab Project No. 6-95-20-001 Report No. 144

METHOD FOR STUDYING PERFORMANCE ON A SIMPLE TRACKING TASK AS A FUNCTION OF RADIUS AND LOADING OF CONTROL CRANKS

A. A. Gerall, P. B. Sampson and S. D. S. Spragg
Dept. of Psychology, Univ. of Rochester

18 pp & ii 12 illus. 5 April 1954

UNCLASSIFIED

Four trained subjects were tested on a simple tracking task in which the operator was required, by using two hand cranks, to align a follower on a stationary target suddenly appearing on the face of a cathode ray oscilloscope. Three crank radii (2, 4, and 6 inches), and five frictional forces (3, 6, 9, 12, and 15 pounds) were used. The results of this preliminary experiment showed that reactions varied with friction but not with crank radius, that travel times and total times were significantly related to crank radius and friction. Adjustment times were not analysed.

1. Psychology 2. Human Engineering 3. Manual Dexterity

Army Medical Research Lab Project No. 6-95-20-001 Report No. 144

METHOD FOR STUDYING PERFORMANCE ON A SIMPLE TRACKING TASK AS A FUNCTION OF RADIUS AND LOADING OF CONTROL CRANKS

A.A. Gerall, P. B. Sampson and S. D. S. Spragg
Dept. of Psychology, Univ. of Rochester

18 pp & ii 12 illus 5 April 1954

UNCLASSIFIED

Four trained subjects were tested on a simple tracking task in which the operator was required, by using two hand cranks, to align a follower on a stationary target suddenly appearing on the face of a cathode ray oscilloscope. Three crank radii (2, 4, and 6 inches), and five frictional forces (3, 6, 9, 12, and 15 pounds) were used. The results of this preliminary experiment showed that reactions varied with friction but not with crank radius, that travel times and total times were significantly related to crank radius and friction. Adjustment times were not analysed.

1. Psychology 2. Human Engineering 3. Manual Dexterity

Army Medical Research Lab Project No. 6-95-20-001 Report No. 144

METHOD FOR STUDYING PERFORMANCE ON A SIMPLE TRACKING TASK AS A FUNCTION OF RADIUS AND LOADING OF CONTROL CRANKS

A.A. Gerall, P. B. Sampson and S. D. S. Spragg
Dept. of Psychology, Univ. of Rochester

18 pp & ii 12 illus. 5 April 1954

UNCLASSIFIED

Four trained subjects were tested on a simple tracking task in which the operator was required, by using two hand cranks, to align a follower on a stationary target suddenly appearing on the face of a cathode ray oscilloscope. Three crank radii (2, 4, and 6 inches), and five frictional forces (3, 6, 9, 12, and 15 pounds) were used. The results of this preliminary experiment showed that reactions varied with friction but not with crank radius, that travel times and total times were significantly related to crank radius and friction. Adjustment times were not analysed.

1. Psychology 2. Human Engineering 3. Manual Dexterity

REPORT NO. 144

METHOD FOR STUDYING PERFORMANCE ON A SIMPLE TRACKING TASK AS A FUNCTION OF RADIUS AND LOADING OF CONTROL CRANKS*

by

Arnold A. Gerall,
Philip B. Sampson,
and S. D. S. Spragg

from

Department of Psychology
University of Rochester
and
Psychology Department
ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY

*Subtask under HUMAN ENGINEERING STUDIES, AMRL Project No. 6-95-20-001, Subtask, Control Coordination Problems. Work done at the University of Rochester under Contract No. DA-49-007-MD-326.

Report No. 144
Project No. 6-95-20-001
Subtask AMRL S-1
Contract No. DA-49-007-MD-326
MEDEA

ABSTRACT

METHOD FOR STUDYING
PERFORMANCE ON A SIMPLE TRACKING TASK AS A FUNCTION
OF RADIUS AND LOADING OF CONTROL CRANKS

OBJECT

To construct a two-hand tracking apparatus suitable for study of the speed and precision of operator performance on simple and on continuous tracking tasks as a function of control characteristics; and to demonstrate the usefulness of this apparatus by means of a preliminary experiment on operator performance in a simple tracking task as a function of the radius of the control cranks and of their frictional loading.

RESULTS

The construction and functioning of the apparatus is described.

Four trained subjects were tested on a simple tracking task in which the operator was required, by appropriate cranking of the two-hand cranks, to move a target follower into alignment with a suddenly appearing stationary target on the face of a twin-beam cathode ray oscilloscope display unit. Three crank radii (2, 4, and 6 inches) and five frictional forces (3, 6, 9, 12, and 15 pounds) were used in a repeated measurement experimental design. The following measures of operator performance were obtained: reaction time, travel time, adjustment time, and total time.

The results of this preliminary experiment showed that: 1) Reaction times, as measured here, varied with force required, but not with crank radius; 2) adjustment times proved to be infrequent and insignificant in this experiment and were not analyzed; 3) travel times, and also total times, were found to be very significantly related to crank radius and to frictional loading.

CONCLUSIONS

This preliminary experiment demonstrated the usefulness of the tracking apparatus and also provided indications that in a simple two-hand tracking task performance with control cranks of differing radii depends upon the amount of friction present. For low frictions small crank radii produce fastest performance, but for greater amounts of friction larger radii are best.

Submitted 5 April 1954 by:
A. A. Gerall;
P. B. Sampson,
S. D. S. Spragg,
Department of Psychology
University of Rochester

APPROVED: Ray G. Daggs
RAY G. DAGGS
Director of Research

APPROVED: William W. Cox
WILLIAM W. COX
Lt. Colonel, MC
Commanding

METHOD FOR STUDYING PERFORMANCE ON A SIMPLE TRACKING TASK AS A FUNCTION OF RADIUS AND LOADING OF CONTROL CRANKS*

I. INTRODUCTION

It is desirable to have military equipment designed so that a minimal amount of human effort is required to control it. However, in many instances this goal is only partially achieved and in others it is achieved at the sacrifice of space, cost, and simplicity of operation and repair. It is not uncommon to have standby controls which are directly or mechanically coupled to the controlled unit available for use if the usual equipment is impaired. Since effort is often required in automatic units or equipment using amplification of the operator's input and especially in standby units, it is important to determine how the load demand of a physical unit affects the efficiency and accuracy of the human operator of that equipment.

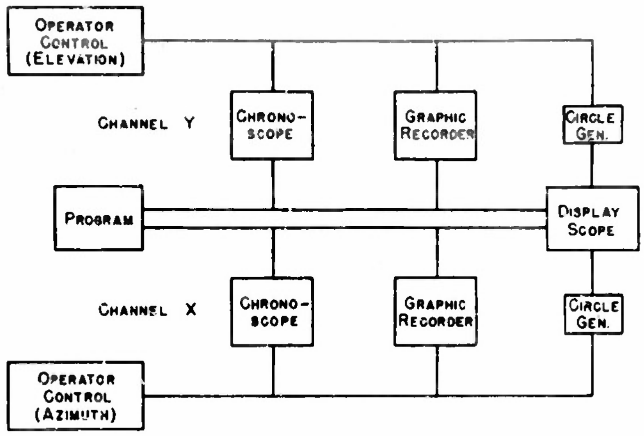
The force required of a human to operate a control is determined by the friction and inertia inherent in the machine, as well as the physical dimensions and location of the control. As the radius of a handwheel control increases, the force demand upon the operator decreases for the same physical load, positions, and inertias. Although increasing the radius of the crank has the desirable effect of decreasing the force requirements, it may produce engineering difficulties as well as an adverse result upon performance. In order to study these variables systematically a tracking apparatus was designed and some experiments have been carried out. The purpose of this report is to describe the apparatus and to report a preliminary investigation of the effect of different crank radii and frictional loadings upon the performance of the human operator.

II. APPARATUS

The purpose of this part of the report is to describe the design and operation of a two-hand tracking apparatus. At present the apparatus is being used in experiments studying simple tracking performance, but the basic design is adaptable to continuous, compensatory and following tracking. The device consists of the following main units: operator's controls, display, programmer, and recorders. Figure 1 presents a block diagram of the functional connection of these units and Figure 2 illustrates in schematic form the electronic details of the circuits. A brief discussion of the operation of the apparatus

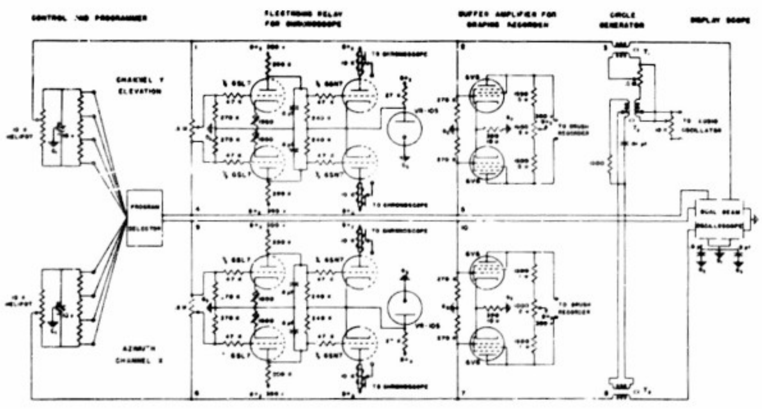
*The authors wish to thank Dr. Charles H. Dawson for his technical assistance in designing the tracking apparatus.

may be helpful before providing some of the details of the design and construction of the components.



BLOCK DIAGRAM

FIGURE I



SCHEMATIC DIAGRAM FOR
CONTROL, DISPLAY AND RECORDING CIRCUITS
FIGURE 2

Two bar cranks are available to the operator for controlling the movement of the target follower, in this case a circle, over the face of a cathode ray tube (see Figure 3). One crank determines the hor-

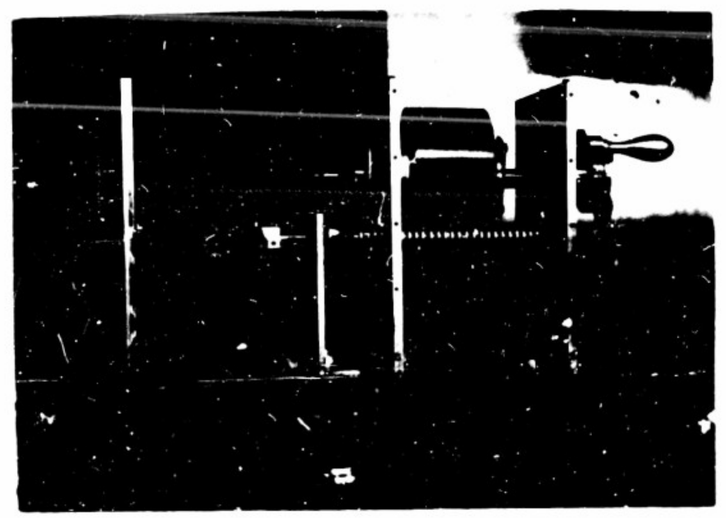
PHOTOGRAPHIC VIEW OF THE OPERATOR'S SIDE OF THE APPARATUS.

FIGURE 3.

izontal position of the follower and the other crank controls the vertical location of the follower. The programmer is designed to present the target, a spot, at various locations on the display unit which is a dual-beam cathode ray tube (CRT). When the target appears, the operator rotates the cranks until the follower encircles the spot. A short time after he accomplishes this simple positioning task, the follower and target disappear from the CRT until a new displacement is presented. Two circuits are included to obtain information concerning the performance of the operator. Electronic relays are used to activate Standard Electric Chronoscopes which record time off target in either the horizontal or vertical directions. A second circuit provides a permanent graphic record of performance. A voltage corresponding to the difference in spatial location between the follower and target is amplified and fed into a Dual Channel Brush Oscillograph. The direction and magnitude of the operator's errors are continuously registered on chart paper moving at a constant speed. The only task of the experimenter during an experimental period is to record time off target from the chronoscopes. In the following paragraphs a more detailed discussion of the components of the apparatus will be presented.

A. Control Unit

The control unit consists of two adjustable bar cranks which can be located in several positions and planes. Rotation of a crank governs the movement of the follower in either the horizontal or vertical direction on the CRT. The cranks are coupled to the shafts of electromagnetic clutches. By varying the current passing through the coils of the clutches, different frictions (mainly coulomb friction) are obtained. Approximately 0 to 10 ft. lbs. of torque can be secured with a precision of 10%. The movement of the shaft is transferred by means of a pulley system to a helipot and a protective stopping unit. This unit locks at the end of 12 turns in either direction from the center of the helipot. If the crank is rotated more than 12 turns from the center, the 'locking' unit causes the pulley from the crank shaft to the helipot to slip, thereby permitting the operator to continue turning the crank without extending the sliding arm of the helipot beyond its end point. A frontal view of the control unit described above is shown in Figure 4.



CONTROL UNIT. THE FOUR MAIN UNITS ARE THE HELIPOT, LOCKINGUNIT, ELECTROMAGNETIC CLUTCH AND BAR CRANK UNIT
FIGURE 4

B. The Display

The display is presented on the face of the cathode ray tube of a DuMont Type 322 Dual-Beam Oscillograph. One beam of the second channel is focused to a spot and is employed as the target. The task of the subject is to place the follower over the target by the appropriate rotation of the cranks. The circuits used to achieve this display are shown in Figures 2 and 6.

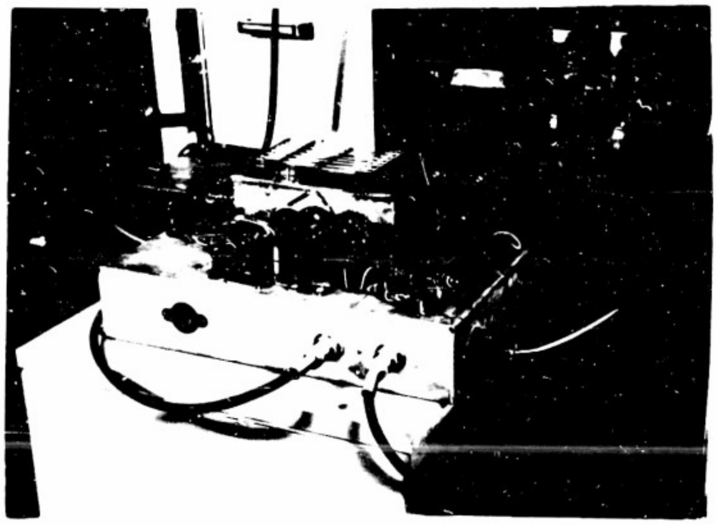
The location of the target or follower on the scope is determined by the DC potential available to the oscillograph. The vertical displacement of both the follower and the target is determined by one parallel resistance network. An identical network controls the horizontal location of both the target and the follower. This network consists of a 10,000 ohm potentiometer in parallel with nine resistors in series equalling 10,000 ohms, and a 15 volt center-tapped DC supply. Hence, by moving the arm of the helipot or by selecting a particular tap along the series of fixed resistors different potential differences in respect to ground can be obtained. These DC differences are coupled directly to the oscillograph. If a resistor above ground in the "y" channel of the oscillograph is selected, the target appears above the center of the CRT since the center of the DC supply is connected to the ground of the scope. A potential difference would also exist between the lead from the helipot and the lead from the fixed resistor and this would appear on the CRT as a discrepancy in the vertical position between the target and follower. When the sliding arm of the helipot is moved to a position at which the resistance from the arm to ground equals the companion resistance of the parallel network, the potential difference between these input leads to the oscillograph becomes zero. On the face of the CRT the target and follower would be in the same position in the vertical direction. The same description, of course, would apply to the network used to control the displacements in the horizontal direction.

A circle generator is placed along the leads from the helipots to the oscillograph. The generator consists of an audio oscillator which produces a 3500 cycles per second signal and a resistance capacitance circuit phase splitting network. The outputs of the resistance capacitance circuit network are two identical voltages except that one is 90 degrees out of phase with the other. By means of transformer coupling one of these voltages is transferred to the lead from the operator's circuit going to the horizontal deflection plate of the oscillograph and the other voltage to the vertical deflection plate. Hence the DC signal from the operator's circuit is modulated by two alternating voltages which are 90 degrees out of phase with each other.

This provides a lissajou figure which is a circle for this phase difference. Also, the modulating voltage has no influence upon the position of the circle on the CRT which is solely determined by the DC signal from the helipot in the operator's circuit.

C. Programmer

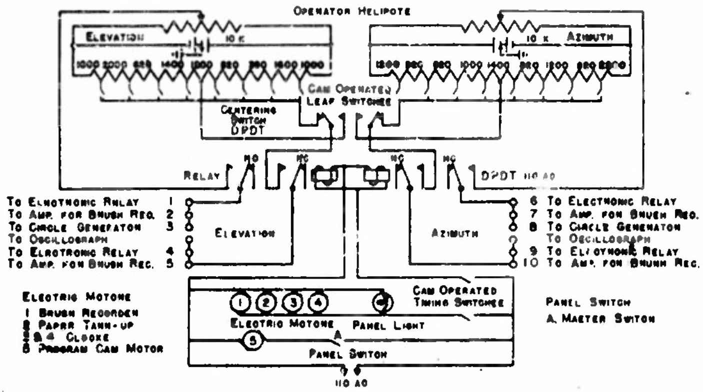
The programmer determines the location or displacement of the target on the face of the CRT. It also controls the inter-trial interval, the blanking of the scope and the operation of the Brush Oscillograph and chronoscope motors. Figure 5 shows the physical



PROGRAMMER FOR SIMPLE POSITIONING TRACKING STUDIES

FIGURE 5

construction of the unit and Figure 6 presents a schematic representation of the electrical components. A point along the series of fixed resistors is selected by means of cam operated lever switches. A lever switch in the normally open position is connected to each of eight positions on this resistance network. A given resistor is selected when a cam closes its lever switch and connects it to the oscillograph circuit. The rotation of the cams is controlled by a constant speed motor. Hence eight different displacements can be presented successively at fixed



PROGRAMMING UNIT

FIGURE 6

intervals. A grooved drum is mounted on the same shaft to which the cams are connected. Microswitches balanced on this drum operate the blanking relays and the AC of the Brush and chronoscope motors. When a lever switch is disengaged from a cam, a micro-switch closes and de-energizes two relays. Then the contacts of these relays are released and all inputs to the oscillograph are opened leaving only two small blurred patches on the scope. Another microswitch which completes the AC circuit for the motors of the recording units closes several seconds before a displacement is shown to the operator.

D. Recorders

It was considered desirable to have a graphic record of the operator's movements as he manipulated the follower as well as an immediate indication of the time the follower was not on target. Two electronic units both responding to the voltage difference obtained from the operator-program parallel network were designed for the above uses. The circuit diagrams for these units are provided in Figure 2.

The buffer amplifier shown in Figure 2 serves as an isolation unit for the Brush 902-A Dual Channel Oscillograph. An isolation amplifier is necessary since it is important that the recording unit not distort or interact with the operation of any other units in the circuit. The amplifier itself should be relatively stable, i. e., it should not drift when the input to it is held constant nor should it respond differently to identical inputs. It is also advantageous that it be designed as a linear amplifier to facilitate the measurement of records. The input impedance of the amplifier employed in this apparatus was sufficiently high so as not to affect the other units. It also met the stability and linearity characteristics mentioned above to a satisfactory extent. The circuit for the buffer amplifier, as shown in Figure 2, is a single stage of push-pull amplification. The output of each amplifier is applied directly to one magnetic pen unit of the Brush Oscillograph. Thus a continuous record of the location of the follower in reference to the target is obtained for each control.

The electronic relay is used to meet the requirement of having an immediate indication of the time the subject is off target. If the follower is positioned over the target no potential difference exists between the control and program leads to the DuMont Oscillograph, (Figure 2: points 1 and 4, and 6 and 9). This is the condition for which the Standard Electric Chronoscopes would be stopped. When the follower is off the target a potential difference exists between the aforementioned points and this voltage is used as a signal for the operation of the chronoscopes. The circuit which responds to this signal or voltage is also provided in Figure 2. When no potential difference exists between the control grid and cathode of the input tube, 6SL7, current flows through this tube. The plate voltage of the 6SL7 provides bias for the 6SN7 of the next stage. If the plate current through the 6SL7 is of a certain magnitude then the voltage on the grid of the next tube will not be high enough to permit an amount of current sufficient to actuate the relay in its plate circuit. If a negative signal is provided to the input of the circuit, the 6SL7 conducts less current which in turn raises the grid voltage on the 6SN7. The subsequent increase in plate current through the 6SN7 may be enough to cause the relay to be energized. The input voltage necessary to activate the relay is established by adjusting the cathode resistors to the 6SL7's. Four relays, one for each half of the 6SN7's are available so that time off target in any of the four quadrants could be recorded, if desired. However, for the first experiment only errors in the vertical and horizontal position, regardless of direction, were desired.

Certain limitations of the present equipment should be mentioned. First, the success of the recording units depends upon their internal stability, and the stability of the cathode ray oscillograph. If for some reason the target or follower drift from their original settings, then there will be recording errors. This means that even though the operator sees the target and follower as being coincidental on the CRT, there will be an error voltage present and the recording units will respond to it. By permitting the apparatus to warm up for at least thirty minutes before starting the first operator and by checking the oscillograph between each operator, the drift factor is sufficiently controlled. However, further improvement in the overall stability of the apparatus is desireable, and is being studied.

Secondly, the electronic relay device employed in the first study (simple positional tracking) would not, without modification, be adequate for other dynamic tracking investigations. The relay circuit used in the apparatus would not be adequate if overshooting or very fine adjustments were important. This is due to a characteristic of relays. The energizing voltage of a relay is greater than its de-energizing voltage. The circuit was adjusted so that the relays would be de-activated when the outer edge of the follower just met the target. However, if the follower moved off target, the relays would not be re-activated until there was about two tenths of an inch discrepancy between them. This "dead time" can be reduced by adding another stage of amplication before the relays or perhaps by using more sensitive relays. This improvement is necessary if precise continuous tracking measures are to be obtained with chronoscopes. In the study to be reported there was very little overshooting of the target or adjustment of the follower because of the torque and control-follower movement ratio required in this study.

Thirdly, the electro-magnetic clutches, at least as used in the present equipment, have certain undesirable features. The calibration of the friction on the shaft changes considerable depending upon the mounting position of the unit. Also the manner in which the brushes are placed on the commutators seems to be highly critical. Faulty placement of the brushes causes a fluctuation in the current passing through the field coils of the clutch mechanism. Furthermore at higher torque demands, static friction becomes greater than coulomb friction, thereby making it more difficult to start cranking than to keep cranking. In the present investigations the frictions studied were below the values in which static friction becomes significant.

E. Applications

An advantage of this apparatus is adaptability to a wide range of perceptual-motor performance research. With appropriate modifications it can be adapted to the study of continuous tracking tasks.

Also, there is a wide range of programs that can be applied to the CRT without much difficulty. The use of a dual-beam oscillograph also permits the ratio between control movements and the consequent changes in the follower to be easily varied. This is accomplished by changing the amplification settings on the oscillograph. The time the display is on can be controlled over wide limits. Also, by modulating the intensity of the program signals, the display can be made to be intermittent.

It is also possible to modify the apparatus so that different types of control units can be investigated. At present, it is being used to study handwheel operation under various torque conditions and in various positions in reference to the body. However, many other types of controls, such as joy stick, knob controls, etc., could be used as well.

III. EXPERIMENTAL

A. Statement of Problem

The purpose of this preliminary experiment was to determine the relationship between performance on a simple two-hand tracking task and radius of control cranks as well as force necessary to rotate the cranks.

B. Experimental Design

1. Apparatus and Subjects - A detailed account of the apparatus is provided in the preceding section. In the study to be discussed the crank controlling the movement of the target follower in the horizontal direction was on the right-hand side of the operator and rotated in the horizontal plane. Another crank controlling the displacement of the follower in the vertical direction rotated in the vertical plane on the other side of the operator. The position of the cranks is illustrated in Figure 3. The task of the operator on each trial was to rotate the cranks as quickly as possible until the follower encircled the target.

The face of the CRT was approximately twelve inches from the subjects' eyes. One revolution of the crank moved the follower through approximately one degree of visual angle. Twenty revolutions of the crank caused the follower to traverse four inches on the CRT.

2. Procedure - Five forces and three radii of cranks were used in the study. They were as follows: 3, 6, 9, 12, and 15 pounds, and 2, 4, and 6 inches. A repeated measurement design with four replications was employed. These four measurements are indicated as Series A, B, C and D. During one experimental session an operator used one crank radius with each of the five forces. Each operator was assigned a different sequence of the fifteen experimental conditions. Under each condition the program consisted of eight different displacements of the target presented in the same order. The displacements consisted of different vertical and horizontal components and occurred in all quadrants on the face of the CRT.

Four staff members of the Department of Psychology at the University of Rochester participated as operators in the experiment, each serving twice a day for six days.

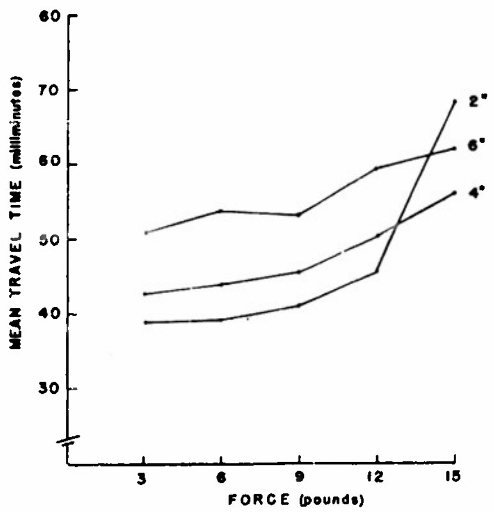
The data to be reported were obtained from the graphic records from the Brush Oscillograph since this afforded a more detailed analysis of the operators' performance than did the clock scores. Three scores were obtained from each record: reaction time, travel time, and adjustment time. A reaction time score was determined by measuring the interval between the appearance of the target and the operators' first recorded movement of the control. The time taken by the subject to reach the target after the initial movement occurred was called travel time. Any overshooting of the target and the duration of readjustments thereafter was tabulated as adjustment time. The three scores combined equalled the total response time. Although the records of each hand were analyzed separately, the score from the hand which took the longer total time to reach the target was used in the statistical analysis of the data. This score represents the time it took the subject to get on target.

C. Results

The primary aim of this study was to relate force demand and radius of cranks to performance of "experienced" operators, hence the results from the last replication of the experimental design, Series D, will be discussed first. In this last series only 5% of all the records showed any measurable adjustment times. Since adjustments after the target had been reached occurred so infrequently during the series no separate analysis of them will be presented.

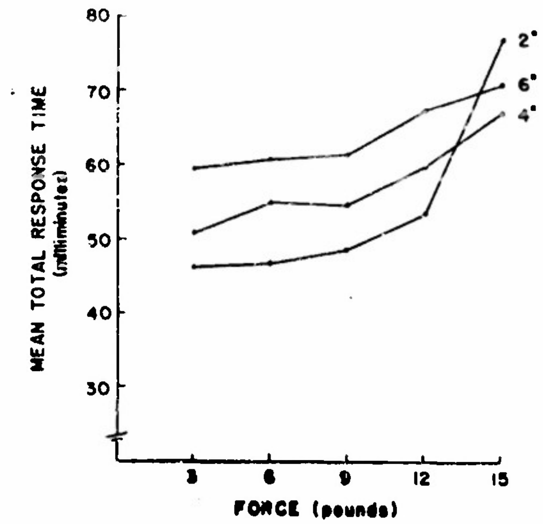
The means of reaction times for all experimental conditions are given in Table 1. The results of an analysis of variance of reaction time is provided in Table 2. Reaction time obtained from the record is significantly related to the force required to turn the crank but not to the radius of the crank.

An analysis of the data for travel time (Table 3) indicates that both crank radius and force demand upon the subject influenced performance to a significant amount. The F-ratios of these variables are presented in Table 4 and the graphs of the corresponding performance are provided in Figures 7 and 8. Although there is no statistically reliable overall interaction among the conditions it appears upon inspection of the graph in Figure 8 that there is an interaction attributable to at least one experimental condition. The performance with the 2 inch crank when 15 pounds of force was required to turn it deviated markedly from the general trend established by the other experimental conditions. It appears that the 2 inch crank produced the fastest tracking times in comparison to larger cranks for forces up to 12 pounds. After this value was reached the 2 inch crank was associated with a more marked decline in performance with increased load demand in comparison to larger cranks. Another way of describing these results is shown in Figure 9. The abscissa in this graph is torque in inch-pounds. The curves indicate how performance changes for a given crank size with increases in torque.



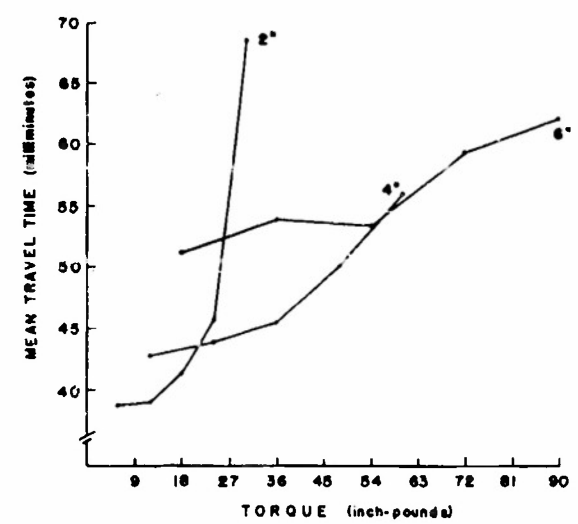
MEAN TRAVEL TIME FOR FORCES AND RADII

FIGURE 7



MEAN TOTAL RESPONSE TIME FOR FORCES AND RADII

FIGURE 8



MEAN TRAVEL TIME FOR TORQUES AND RADII

FIGURE 9

TABLE 1

MEAN REACTION TIME IN MILLIMINUTES FOR SERIES D

Force (lbs.)	Crank Radius (inches) 2	4	6	Mean
3	5.5	5.6	6.2	5.8
6	5.6	7.1	6.6	6.4
9	6.7	6.4	6.6	6.6
12	6.8	6.4	7.5	6.9
15	7.0	7.6	8.0	7.5
Mean	6.3	6.6	7.0	6.6

TABLE 2

ANALYSIS OF VARIANCE OF REACTION TIME FOR SERIES D

Source of Variation	df	Mean Square	F
Subjects	3	70.3	5.28**
Cranks	2	21.3	1.60
Forces	4	51.3	3.85*
FxS	12	2.9	.22
FxC	8	5.8	.44
SxC	6	13.6	1.02
SxCxF	24	13.3	--
Total	59	--	--

** P = .01
* P = .05

TABLE 3

MEAN TRAVEL TIME IN MILLIMINUTES FOR SERIES D

Force (lbs.)	Crank Radius (inches) 2	4	6	Mean
3	38.8	42.8	51.2	44.3
6	39.0	44.0	54.0	45.7
9	41.5	45.8	53.5	46.9
12	45.8	50.3	59.5	51.8
15	68.2	56.0	62.0	62.1
Mean	46.7	47.8	56.0	50.2

TABLE 4

ANALYSIS OF VARIANCE OF TRAVEL TIME FOR SERIES D

Source of Variation	df	Mean Square	F
Subjects	3	531.7	10.0***
Cranks	2	528.0	9.9***
Forces	4	631.8	11.8***
FxS	12	53.0	1.0
FxC	8	90.9	1.7
SxC	6	78.0	1.5
SxCxF	24	52.5	--
Total	59	--	--

*** P = .001

It is of interst to determine whether the functional relationships found between performance as measured by travel time and the various experimental conditions also hold when reaction, travel and adjustment times were considered as a single measure--total response time. The data for this measure and the analysis are presented in Tables 5 and 6. In general the analysis indicates that the same differences found with travel time also hold for total time.

TABLE 5

MEAN TOTAL RESPONSE TIME IN MILLIMINUTES FOR SERIES D

Force (lbs.)	Crank Radius (inches) 2	4	6	Mean
3	46.5	50.4	59.5	52.1
6	47.2	54.2	60.7	54.0
9	48.9	54.1	60.4	54.5
12	53.9	57.1	67.5	59.5
15	76.9	66.2	70.5	71.2
Mean	54.7	56.4	63.7	58.3

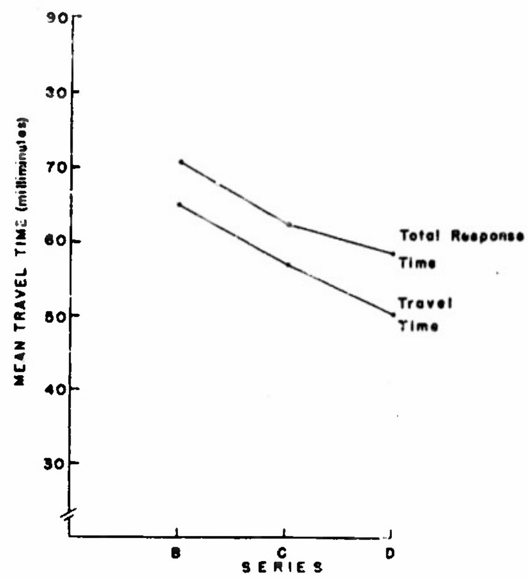
TABLE 6

ANALYSIS OF VARIANCE OF TOTAL RESPONSE TIME FOR SERIES D

Source of Variation	df	Mean Square	F
Subjects	3	494.8	9.2***
Cranks	2	461.8	8.6**
Forces	4	715.4	13.3***
FxS	12	61.8	1.15
FxC	8	87.2	1.62
SxC	6	106.7	1.98
SxCxF	24	53.6	--
Total	59	--	--

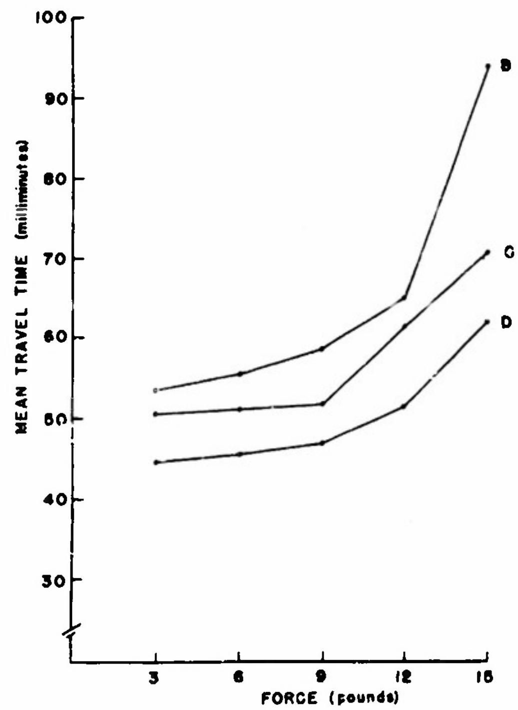
*** P = .001
** P = .01

Each operator served in all experimental conditions four times (Series A, B, C and D). In order to evaluate the effect of practice upon the performance of this task the means of the last three series are presented in Figure 10. The scores of the first replication (Series A) were not used because the recording circuits were readjusted during this series. These curves clearly show that there is improvement in performance with practice as measured by a decrease in time to get on target for this task. However an inspection of Figures 11 and 12 also indicates that the relation between the experimental conditions and performance is essentially maintained during all of the practice series. This would indicate that there is little or no interaction between practice and experimental conditions.



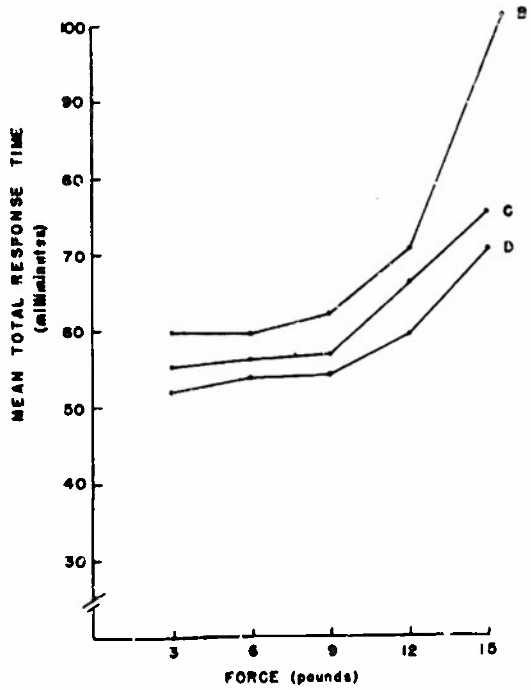
MEAN PERFORMANCE TIME FOR SERIES
AND TYPES OF TIME SCORES

FIGURE 10



MEAN TRAVEL TIME FOR FORCES AND SERIES

FIGURE 11



MEAN TOTAL RESPONSE TIME FOR FORCES AND SERIES

FIGURE 12

IV. DISCUSSION

Since this study was intended to be a preliminary investigation, the range of values of crank radii and forces was limited and the subjects were not selected randomly from the general population. Thus the generalizations from it must be restricted until further experimentation on a larger and more representative sample is completed.

The infrequency of adjustment time scores in this experiment is probably due to the relatively large ratio between control movement and follower movement. This condition, according to the results of Jenkins and Connor (1), leads to minimal adjustment times for some tasks. It is also reasonable to expect that the friction used in this experiment would tend to decrease the degree of overshooting. Reaction time also was a small part of the total tracking time. However, it appears that reaction time of the operators, as measured here, was proportional to the force required to turn the cranks.

Most attention was paid in the result section to an analysis of travel time because it incorporated the largest part of the total time to get on target. It also appears that the results of travel time and total time are alike. These results, as shown in Figure 9, indicate that the radius of control crank which would produce optimal performance depends upon the torque or friction inherent in the system. An operator is able to get on target in less time with the smaller cranks than with larger cranks for low values of torque. Larger cranks are necessary if the torque is increased beyond a certain value. Research in progress should provide a more adequate estimate of the range of torques for which a given size crank would be best suited. The results also suggest that in systems in which the torque is irregular or variable that the larger size crank would lead to the most homogeneous performance. This is indicated in Figure 9 in which the curve for the 6 inch cranks shows relatively little slope.

Increasing the coulomb friction on the control cranks produced a decrement in performance under all conditions. This finding is in agreement with those found in other investigations (2). The data of experiments on a larger group of subjects should provide a more generalizable quantitative description of the functional relationship between performance and coulomb friction.

V. CONCLUSIONS

Performance on a simple two-hand tracking task is inversely related to the coulomb friction inherent in the control system.

Performance on this task with different sizes of cranks depends upon the friction of the system. Small radii are appropriate for small amounts of friction and inappropriate for larger amounts of friction. Larger size cranks are necessary as the friction increases.

VI. BIBLIOGRAPHY

1. Jenkins, W. L. and M. B. Conor. Some design factor in making settings on a linear scale. J. Appl. Psychol., 33: 395-409, 1949.

2. Helson, H. Design of equipment and optimal human operation. Am. J. Psychol., 62: 473-497, 1949.